WHAT HAPPENS IF THE STARS GO OUT?
U.S. ARMY DEPENDENCE ON THE
GLOBAL POSITIONING SYSTEM

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by

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The opinions and conclusions expressed herein are those of the student author and do not necessarily represent the views of the U.S. Army Command and General Staff College or any other governmental agency. (References to this study should include the foregoing statement.)

ABSTRACT

WHAT HAPPENS IF THE STARS GO OUT? U.S. ARMY DEPENDENCE ON THE GLOBAL POSITIONING SYSTEM, by LCDR Thomas M. McGrath, 82 pages.

Dependence on technological superiority should prompt many questions. What if the Army cannot use the Global Positioning System (GPS) data or it is degraded? Are the troops trained to operate when GPS systems are degraded? What about the precision guided munitions that hit exact coordinates to prevent collateral damage? Are commanders planning for the possible loss of systems that provide them global reach and awareness? This thesis attempts to determine if the U.S. Army is unbalanced in its dependence on GPS and if degraded system conditions will deny mission success. Descriptive and historical analysis, as well as a survey of Army field-grade officers indicated a heavy reliance placed on GPS, but the available evidence did not indicate over dependency. A point to note is that, as with any consideration of technology, this thesis is a snapshot in time.

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TABLE OF CONTENTS

ACRONYMS

BFT	Blue Force Tracker
COMPASS	Global Navigation Satellite System (Chinese)
EMP	Electromagnetic Pulse
FM	Field Manual
GAO	Government Accounting Office
GLONASS	Global Navigation Satellite System (Russian)
GPS	Global Positioning System
JCS	Joint Chiefs of Staff
NAVSTAR	Navigation Signal Time and Ranging
TTP	Tactics, Techniques, and Procedures

ILLUSTRATIONS

CHAPTER 1

INTRODUCTION

The purpose of this thesis is to consider whether or not the U.S. Army is overly dependent on global positioning system (GPS) information to the point where fighting through the loss of that technology would be prohibitively expensive – in terms of time, money, operational capability, or lives. There is a culture of reliance on technology throughout the modern world. The U.S. Army has gone from using a map and compass to navigate to using satellite navigation in weapons systems, land navigation, and command and control systems. In a speech at the LANDWARNET 2008 conference, General Chilton, United States Strategic Command (USSTRATCOM) Commander, stated:

> Now I don't know about you, but I remember back in '89, '90 when I had that first computer and I'd double click on an icon to open up something, and it would take two or three seconds before it would open up. Now if it takes more than a nano-second I get pretty frustrated. In fact I'm on the phone calling my IT specialist and saying get in there and fix my computer. It ain't happening fast enough. (Chilton 2008)

While General Chilton's remarks speak to computers, the broader implication is that technology is a necessity. While encryption and security are extremely difficult to overcome, there are adversaries, non-state actors, hackers, and criminal organizations, whose sole purpose is to deny the U.S. Army use of its technology. General Chilton went on in his speech to state: ―. . . remember, the network's global, and a vulnerability in the headquarters, a vulnerability in the Pentagon can translate into a vulnerability on the other side of the world or a disaster on the other side of the world." The simple statement is that with global technology and capability come global risk.

Dependence on technological superiority should prompt many questions. What if the Army cannot use GPS or it is degraded? Are the soldiers trained to operate when GPS

systems are degraded? What about the precision guided munitions that hit exact coordinates to prevent collateral damage? Are commanders planning for the possible loss of systems that provide them global reach? This thesis will attempt to determine if the U.S. Army is unbalanced in its dependence on GPS and if degraded system conditions will deny mission success.

Background

Having the technology advantage in any size conflict directly contributes to the advantage sought by the battlefield commander. U.S. Army Field Manual (FM) 3-0, *Operations*, states that “Technology, having played an increasingly important role in increasing the lethality of the industrial age battlefield, will assume more importance and require greater and more rapid innovation in tomorrow’s conflicts” (Department of the Army 2008b, 1-89). Technology continues to outpace the development of doctrine with rapid fielding of systems becoming the norm, to retain technological advantage.

> The first GPS satellite was placed in orbit in 1978. When the U.S. Army deployed for Operation Desert Storm in 1990, 16 NAVSTAR satellites were in orbit providing guaranteed three-dimensional coverage lasting about 19 hours. The new [GPS] devices had a built in error of only 60 feet compared to land based systems with up to eight miles expected error. By 1995, all 24 NAVSTAR satellites were in orbit, providing world-wide coverage 24 hours a day. (Dissinger 2008, 1)

Leaping forward to Operation Iraqi Freedom, “Most military aircraft use GPS, and the U.S. Army uses over 100,000 GPS units. Eventually, every precision-guided munition will use GPS navigation (Adams 2001, 11). The accuracy of the GPS receiver has continuously improved over the past 20 years. Now, even commercial GPS units can consistently and reliably establish a user’s position within a few feet. As with any technology, consistency and reliability are cornerstones to applications on the battlefield.

Another key to technology is cost. With limited funds, training on advanced technology has become a focus during reset periods. Less time is spent on the manual techniques of map reading and land navigation which are required to back up the automated methods if they fail or are rendered unreliable through jamming, spoofing, or space weather effects. –Regardless of the clear mandate from these documents [National Security Strategy] the Army is focused on training for stability operations and is losing expertise in traditional offensive and defensive operations which maintain the ability to defeat traditional maneuver battle threats" (Diano 2007, 40). Battle Command Systems, with GPS input, automatically track patrol locations and report them in real-time to the Commander. While this gives the commander the picture he needs to make decisions on force employment, one wonders how this process would be affected if he could not trust the picture. Members of the Army's Command and Control Directorate (C2D) at Fort Monmouth, NJ, stated the deficiencies of GPS this way:

> A downside to GPS is its low signal power, making it vulnerable to EMI [electromagnetic interference] and signal blockage. The Air Force Scientific Advisory Board in November of 1993 and the Defense Science Board Task Force on GPS in November of 1995 found that GPS had several deficiencies. The most important deficiency being that it is vulnerable to jamming. The documents describing the jamming threat are the NAVSTAR Global Positioning System (GPS) System Threat Assessment Report (STAR), the National Air Intelligence Center (NAIC) 1574-0407-97 (7 April 1997) and the NAIC 1574-0407-99 (1 Jan 1999) which validated the GPS Star. (Filler et al. 2004, 4)

Primary Research Question

Do today's U.S. Army officers believe the U.S. Army has become unbalanced in its dependence on GPS on the modern day battlefield?

Secondary Research Question

What is an appropriate balance between technology and tactics, techniques, and procedures (TTPs) to allow the U.S. Army to fight through a degradation of GPS?

Significance

Technology and the U.S. Army are bonded together and with the proliferation of GPS jamming and spoofing technologies, that bond will be severely tested in the future. With the exponential rise in cost to obtain cutting-edge technology and a limited budget to cover long term commitments, the U.S. Army needs to be aware of the risk of vulnerabilities in its “electronic armor.” The Chinese military strategy clearly acknowledges the United States dependence on GPS technology.

> Among many complex and diverse lessons, Chinese analyses of US military operations in the Persian Gulf wars, Kosovo and Afghanistan have yielded one critical insight: the United States is inordinately dependent on its complex but exposed network of sophisticated command, control, communications and computer-based intelligence, surveillance and reconnaissance systems operating synergistically in and through space. In other words, while American military power derives its disproportionate efficacy from its ability to leverage critical space assets, these very resources are simultaneously a font of deep and abiding vulnerability. Chinese strategists concluded, therefore, that any effort to defeat the United States would require a riposte against its Achilles heel: its space-based capabilities and their organic ground installations. (Tellis 2007)

Assumptions

1. Adversaries will continue to exploit off-the-shelf hardware and software vulnerabilities.

2. Technology on the battlefield can be compromised through action by the adversary or by friendly forces.

Limitations

In conducting this research on GPS technology dependence, sources were limited to unclassified documents that discuss vulnerabilities of U.S. Army current and future GPS technology. Also, with regard to the survey conducted, availability of personnel to participate was limited by time and resources. It must also be acknowledged that in dealing with qualitative research, even though numerical results are provided, opinions are the foundation data for the analysis conducted.

Delimitations

This thesis focuses on the technological dependence of the U.S. Army on GPS. Mention was made of other services, specifically the U.S. Air Force, but only with respect to their responsibility for GPS operation and support.

CHAPTER 2

LITERATURE REVIEW

This review conducted research into the trend of GPS usage in the Army, GPS technology vulnerabilities, and scenarios in which GPS has become a critical factor of mission success. In addition, the field of qualitative analysis was explored for an appropriate research methodology. The number of publications on GPS technology and its survivability and dependability are increasing on a daily basis. When the qualifiers “U.S. Army” and “battlefield” are added, the list shrinks considerably. Most of the information found originates from military theses, Defense periodicals, and military doctrine. Additional information on vulnerabilities is available, although due to its classification, it is restricted to specific cleared audiences.

The upward trend of GPS usage and application within the Army began with Operation Desert Storm, where 500 commercial handheld devices were issued to deploying units (Dissinger 2008). Fifteen years later, GPS is embedded in almost every command and control system the Army operates and the Department of Defense (DoD) has a military-developed handheld GPS device that is hardened against jamming and interference called the DAGR (Defense Advanced GPS Receiver). The trend of countries investing in their own GPS satellite systems has increased as well. For a number of years, Navigation Signal Time and Ranging (NAVSTAR), the U.S. GPS System, was the only fully operational GPS available in the world. In the past 10 years, Russia, China, and Europe have all established GPS programs. Russia’s program, Global Navigation Satellite System (GLONASS), is the only other program close to global operation, expected in 2010, besides NAVSTAR (GPS World Staff 2009, 1). The NAVSTAR

system that was brought on-line in the 1970s has continued to evolve with the technological advances in satellite power management, frequency encryption, and GPS receiver capability. Advances are critically reviewed for their applicability in such field specific periodicals as *GPS World* and *Space and Technology,* but due to the broad usage of GPS, articles were also seen in such magazines as *Computer World.*

The quarterly newsletter from the Weapons Systems Technology Information Analysis Center (WSTIAC) went into explicit detail with regard to the precision in guidance of munitions as well as anti-jamming and electronic counter -countermeasure methods to combat jamming (M. Scott 2002). While this thesis does not delve into the complex technical background of GPS, the newsletter brought to light the minimal requirements to jam a GPS signal due to the low power output from the satellite. The article authored by Lieutenant Colonel Thomas K. Adams, USA (Ret), entitled *GPS Vulnerabilities* stated very simply that ―. . . a GPS jammer/spoofer that can render GPS receivers inaccurate within a 10-mile radius can be built for less than $400 from parts available at retail stores" (Adams 2001, 14). At the entry into Operation Iraqi Freedom (OIF), Iraqi troops were using a GPS jammer commercially available from the Russian company Aviaconversia which cost less than $4,000 (Gentry 2002, 91).

The GPS signal is vulnerable in the air, on the ground and in space. Most of the vulnerabilities discussed in open sources deal with jamming or spoofing of the ground based GPS receiver. Some discussion has also been arising about defense of the NAVSTAR satellites from shoot down. The current altitude of the NAVSTAR satellites, as medium earth orbit (MEO) satellites, is approximately10,900 miles from earth (NAVSTAR GPS 2001). Comparing the GPS satellite altitude to that of the satellite shot

down by China using a medium range ballistic missile in 2007 at 537 miles, nothing in any country's arsenal can come close to reaching the NAVSTAR GPS Constellation (BBC News 2007). A critical item to note is that while a missile may not reach the GPS constellation, any debris released in space by an adversary with a missile that can go exoatmospheric can conduct anti-satellite operations. One crude method of intentionally damaging orbiting satellites has been documented since the late 1990s in Russian doctrine. ―If a rocket could carry 40 pounds of 00 steel buckshot available in most sporting goods stores it could kick the pellets out into an appropriate orbit with an explosive charge. Moving at relative velocities of about four miles a second, the tiny pellets would slam into and disable any satellite they encountered (Adams 2001, 15). Another possibility of satellite destruction, while not intended, is the ever increasing amount of space debris. The largest space debris incident in history was the Chinese anti-satellite weapon test on 11 January 2007. The event was estimated to have created more than 2300 pieces of trackable debris. The debris event is more significant than previous anti-satellite tests in that the debris field has a higher orbit altitude. NASA's Nicholas Johnson, Chief Scientist for Orbital Debris at the space agency's Johnson Space Center stated, ―This satellite breakup represents the most prolific and serious fragmentation in the course of 50 years of space operations" (David 2007).

Joint Vision 2020 and U.S. Army doctrine were an excellent source of information with regard to the current operating environment and how GPS is used throughout the Army. *Joint Vision 2020* clearly pointed out that the asymmetric path of attack of our adversaries will continue with U.S. dependence on technology as a key point (Chairman 2004, 4). While it spoke in broad terms, U.S. Army Field Manual 3.0,

Operations directly addressed the role that technology plays on today's battlefield by stating, ―Moreover, the proliferation, falling costs, and availability of technologically advanced products--especially expanded information technologies using mobile networks and expanded use of wireless and global fiber-optic networks--enable nonstate adversaries to acquire them" (Department of the Army 2008b, 1-2). In a review of 13 U.S. Army field manuals (3-01.86, *Air Defense Artillery Patriot Brigade Gunnery Program*; 3-01.87, *Patriot Tactics, Techniques, and* Procedures; 3-04.15, *Multi-service Tactics, Techniques, and Procedures for the Tactical Employment of Unmanned Aircraft Systems*; 3-04.120, *Air Traffic Services Operations*; 3-04.240, *Instrument Flight for Army Aviators*; 3-13.10, *Multi-service Tactics,Techniques, and Procedures for the Reprogramming of Electronic Warfare and Target Sensing Systems*; 3-20.98, *Reconnaissance and Scout Platoon;* 3-21.8, *The Infantry Rifle Platoon and Squad*; 3-21.75, *The Warrior Ethos and Soldier Combat Skills*; 3-25.26, *Map Reading and Land* Navigation; 3-52, *Army Airspace Command and Control in a Combat Zone;* 3-97.6, *Mountain Operations;* 7-1, *Battle Focused Training*) ranging from aviation and weapons tactics, techniques, and procedures (TTPs) to infantry operations, all referenced GPS as a critical tool for their respective operation or mission. All of the field manuals reviewed, except for one, did not mention any cautions or warnings in regard to dependence on GPS data as the sole navigation or position provider. The one manual that did mention a caution was Field Manual 3-20.98, *Reconnaissance and Scout Platoon* by telling the reader to maintain their backup capabilities of land navigation (Department of the Army 2009, D-3).

Review of open source Defense periodicals revealed many articles that evaluate GPS technology but few that address its limitations in military operations. Key scenarios that demonstrate GPS criticality include precision weapons employment, command and control, and fratricide prevention. *Joint Vision 2020* stated that precision engagement is one of the tenants for successful future operations (Chairman 2004). In his paper *Precision Guided Munitions: Panacea or Pitfall for the Joint Force Commander?,* Major Randy Kaufman, USAF, stated, —While precision and near-precision munitions provide distinct capabilities, they are not the sole avenue to success. In many cases, unguided munitions provide the same effects in a more timely manner and with greater economy than guided weapons" (Kaufman 2003, 17). The GAO report, *GPS: Significant Challenges in Sustaining and Upgrading Widely Used Capabilities*, reveals that the future of the GPS constellation is not positive by stating:

> However, DOD predicts that over the next several years many of the older satellites in the constellation will reach the end of their operational life faster than they will be replenished, and that the constellation will, in all likelihood, decrease in size. Based on the most recent satellite reliability and launch schedule data approved in March 2009, the estimated long-term probability of maintaining a constellation of at least 24 operational satellites falls below 95 percent during fiscal year 2010 and remains below 95 percent until the end of fiscal year 2014, at times falling to about 80 percent. See figure 1 (Government Accounting Office 2009).

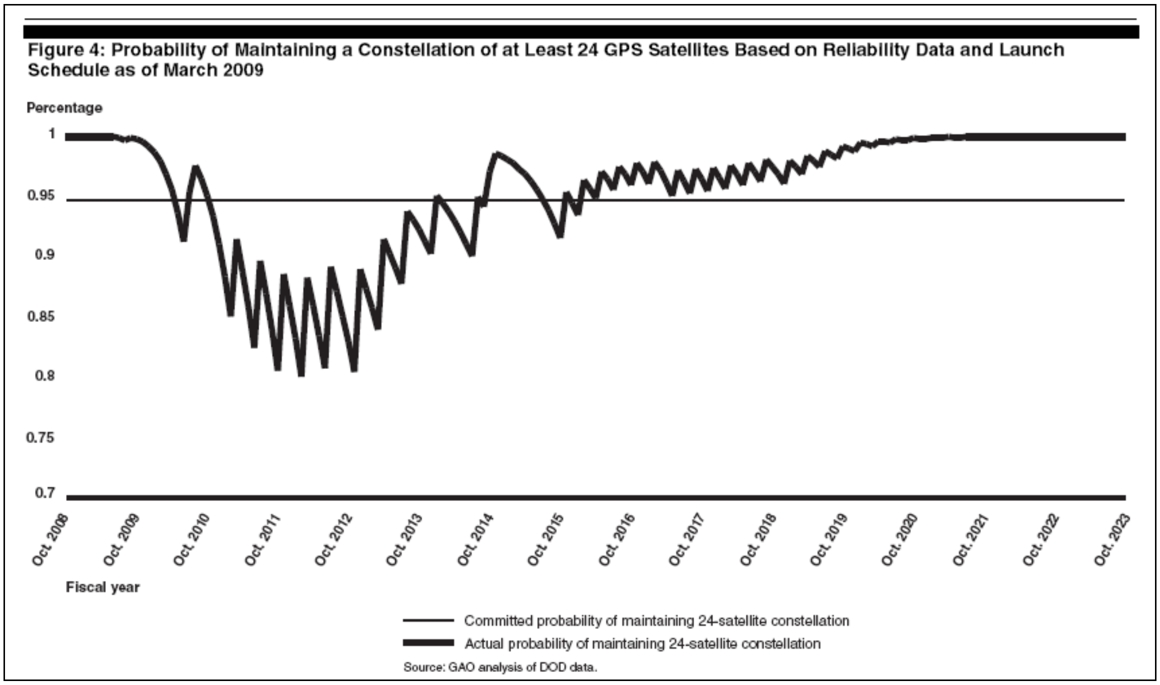


Figure 1. Maintaining a 24 Satellite GPS Constellation
Source: Government Accounting Office (GAO), GAO 09-325, *Global Positioning System* (Washington, DC: Government Printing Office, 2009), 20.

In Command and Control situations, GPS has been integrated mostly for ―own force" tracking in addition to providing timing critical to synchronization of data network information processing. While technology has increased the commander's capability to see and manage his forces, limitations still exist. As stated by Giles Ebutt from Jane's International Defense, ―These blue-force tracking (BFT) systems therefore do not provide a real-time image of the battlefield. While going a considerable way towards force deconfliction, they do not offer fail-safe combat identification. The reliance on GPS can be a disadvantage in the urban environment, where the system is less effective, particularly at the level of the individual soldier inside a building (Ebutt 2008, 1).

Methodology

A key reference for conducting qualitative analysis was *Writing Up Qualitative Research,* 2nd edition, by Harry Wolcott. Mr. Wolcott cautions his readers to qualify their research data so as not to misrepresent its validity or lead the reader to generalize information that does not have a basis in fact (Wolcott 2001, 30). Also, he clearly points out that the analysis “follows standard procedures for observing, measuring, and communicating with others about the nature of what is “there,” the reality of the everyday world as we experience it (Wolcott 2001, 33). Another revelatory point made by Mr. Wolcott was that of the difference between analysis and interpretation. While analysis is based on specified procedures, interpretation is derived from “our efforts at sensemaking, a human activity that includes intuition, past experience, and emotion” (Wolcott 2001, 33). This reference was of extreme value due to its “conversation” writing style in addition to its step-by-step approach to collecting field data, analyzing it, and communicating the results in a coherent fashion.

With regard to GPS data, there is no confusion on the point that it is a necessary technology for the Army’s competitive advantage on the battlefield. While many authors point out the vulnerabilities and gaps with regard to GPS data, some noted that the GPS constellation is quite robust and positioned well for the future. Army doctrine did not address any issues in field manuals with respect to GPS dependency aside from a short comment in one field manual advising soldiers to remember their basic navigation skills as a backup. The future operating environment continues its growth in technological complexity and thus there exists a need for close examination of the Army’s use, application, and management of GPS data. Chapter 3 guides the reader through the

research methodology used to identify these vulnerabilities, the risks associated with the identified vulnerabilities, and the perceptions among field practitioners of the presence and potential impact of those vulnerabilities.

CHAPTER 3

RESEARCH METHODOLOGY

This thesis uses two strategies to analyze research data: qualitatively, a descriptive and historical analysis on the attributes of placing reliance on GPS data; and quantitatively, a survey instrument to evaluate the perceptions and experiences of GPS usage and land navigation training at the Army field-grade officer level. This thesis specifically focuses on the NAVSTAR GPS Constellation operated by the U.S. Air Force and GPS data utilized by the U.S. Army in their navigation, weapon, and command and control systems. The descriptive analysis examines the characteristics that make up the GPS system to develop a clear picture of the system for the reader. The historical analysis looks at the development of the GPS system at milestones from its inception in the 1970s until present day.

In conducting qualitative analysis, guidelines were drawn from the work of Harry Wolcott who stated that ―description is the foundation upon which qualitative research is built' (Walcott 2001, 31). The descriptive analysis builds a clear picture of the GPS system allowing the reader to understand and appreciate its complexities.

―The inductive research mode described by Cresswell details a multi-step process of gathering information, asking questions, forming categories, looking for patterns and developing a theory based on the patterns discovered" (Ward 2005, 157). The historical description develops the picture for patterns while the survey conducted and its subsequent analysis asks the questions to develop the theory and look for patterns.

The quantitative methodology in the research for this thesis is the collected survey data for subsequent quantitative analysis. The survey instrument was developed by the

author of this paper based on his past training in survey development. It was kept short to ensure maximum opportunity for completion by the respondents and to collect only that information necessary to provide data for the research question analysis. The survey application was presented to the human protections administrator for review. It was determined to be exempt from the Institutional Review Board and was approved by the Quality Assurance Office (QAO) of the U. S. Army Command and General Staff College (CGSC) for administration. The survey was assigned control number 09-081 in accordance with CGSC Bulletin No. 40: Survey Research (King 2008). Due to time constraints, the survey was not piloted. Administration of the survey was through the QAO information system, Inquisite, which emailed the survey to all U.S. Army majors within CGSC class 09-02 (266 emails sent). The survey response period was 30 days from the date of initial distribution. One follow-up request for responses to the survey was sent out at the 20 day point. All respondent data was anonymous and by responding to the survey informed consent to participate was granted.

The survey analysis (see Appendix B) attempted to discern if a correlation exists between the three factors of U.S. Army branch, length of service, and last GPS training experience and the effect of GPS loss on mission completion. While the survey was limited in scope to the U.S. Army Majors within Class 2009-02 at the U.S. Army Command and General Staff College, the goal was to obtain a significant sample across a cross-section of Army branches to discern whether or not some type of correlation exists between GPS dependency and mission accomplishment. While the quantitative analysis is based on opinions, the experience of conducting the survey drives directly to the heart of the matter of whether or not the Army is unbalanced in its dependence on GPS data.

“Yet, as Glaser and Strous (1967) argue, it is the intimate connection with empirical reality that permits the development of a testable, relevant and valid theory” (Eisenhardt 2002, 5). The survey asked for subjective responses, but in a manner that enabled quantifying the intensity and distribution of those responses. Quantitative analysis of those responses enables a clearer understanding of the perceptions, and may point the way to further, empirical research.

The survey sought to correlate Army branch, navigation training experience, GPS use in a combat environment, and GPS criticality to mission success. These first three factors are empirical; the responses are clear cut and easily quantified. The fourth factor required a subjective impression or opinion, and as such is much less easily quantified. However, it provided a tool to measure the level of confidence that experienced combat leaders have in the GPS tools at their disposal, and to attempt to correlate that level of confidence to the three empirical factors.

Quantitative data was subjected to statistical analysis appropriate to the data type. This analysis is described in greater detail in chapter 4. Finally, results were analyzed to generate a confidence level, in order to indicate how confident the researcher was that the results of the sampling represented the larger population.

The reader will note that the chi-squared statistical analysis was used in analyzing the data. The chi-squared statistic allows for the analysis of data that does not have a median or standard deviation. The data collected from this survey lent itself to categories which give the chi-squared statistical method the opportunity to determine if correlation between category selections by respondents were either the result of chance or a significant relationship.

The graphical representation of the data found in Appendix B allows the reader to quickly see the survey data and roughly interpret the population of the survey as well as their attributes with respect to branch, time in service, and land navigation training. The bar graph comparison of the data allows for development of situational awareness prior to engaging the more detailed analysis found in the chi-squared statistical reports.

The qualitative and quantitative methodologies discussed aimed to provide the most pertinent data for analysis. Through descriptive and historical analysis, the desire was to both provide clarity to the reader in examination of the GPS system as well as reveal the ever increasing complexities involved with a system as it develops over time. The survey, while narrow in its application, was designed and administered to capture the opinions of a diverse and available audience of U.S. Army majors with respect to land navigation training and use of GPS in the field. Continuing on, chapter 4 presents the analysis of the collected data and its interpretation to the reader.

CHAPTER 4

PRESENTATION AND ANALYSIS OF DATA

Chapter 4 will expand on information derived from the literature presented in chapter 2 and apply the research methodologies outlined in chapter 3 in pursuit of the thesis conclusions and recommendations. In order to develop the picture of the GPS system, descriptive analysis will be utilized to break down its attributes and complexities. In an effort to reveal the trend of GPS usage by the U.S. Army, the literature collected will be subjected to historical analysis to determine if the widespread use of GPS data has developed into dependence. The quantitative analysis of survey data will bring to light the existence of any correlations between the major categories of service branch, navigation training, and mission reliance on GPS.

Descriptive Analysis

The Global Positioning System (GPS), a constellation of satellites (see figure 2) managed by the U.S. Air Force, provides 24/7 coverage of the earth while delivering precision position, navigation, and timing information for both military and civilian users.

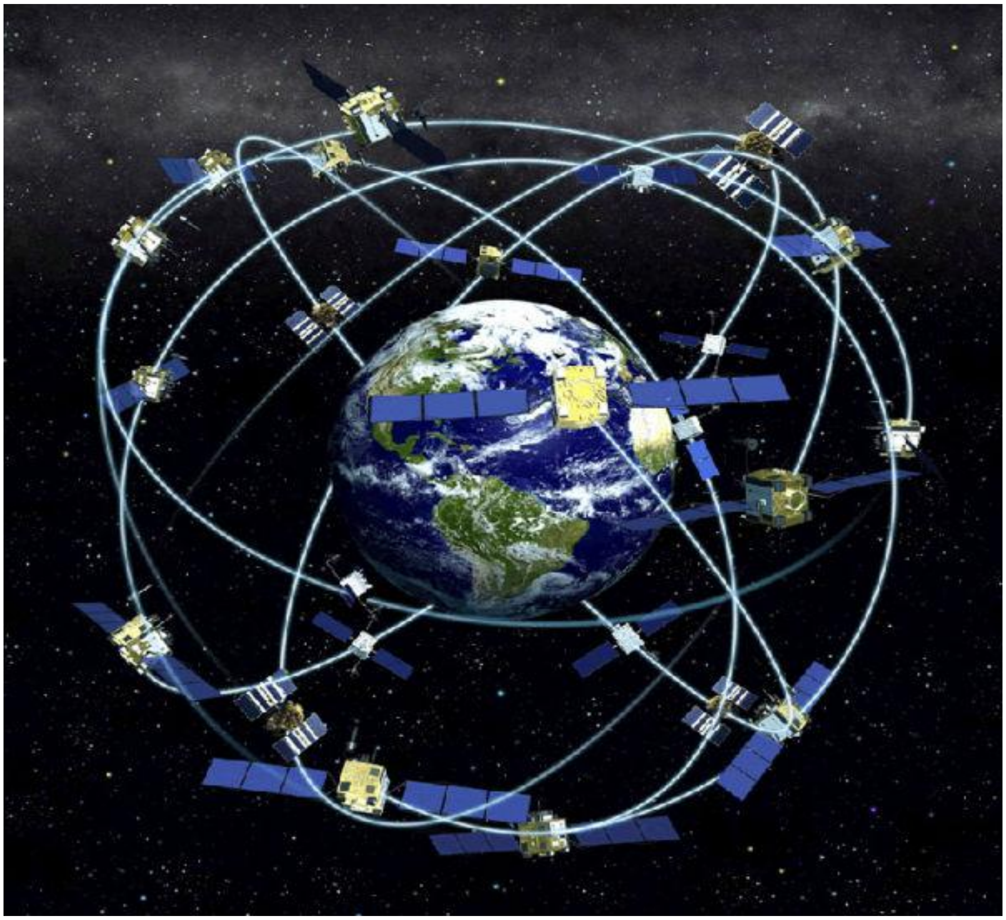


Figure 2. 3D Representation of the GPS Satellite Constellation
Source: GPS-constellation-3D-NOAA.jpg. http://commons.wikimedia.org/wiki/File:GPS-constellation-3D-NOAA.jpg (accessed 30 September 2009).

While GAO report 09-325 stated that the GPS constellation could fall below 95 percent reliability (Government Accounting Office 2009, 20), the performance history of the system indicates otherwise. In his statement before the Congressional subcommittee on National Security and Foreign Affairs, General James, USAF, Joint Functional Component Commander for Space, stated that:

> Although required to maintain 24 GPS satellites on orbit at 95 percent probability, we have exceeded requirements by currently maintaining 30 operational satellites and have achieved sub-three meter accuracy. We conduct ―residual operations" as an on-going solution to mitigate any potential gap in GPS by retaining older,

> partially mission capable satellites in a back-up mode that can potentially be returned to operations if a satellite in the constellation fails. Currently three vehicles are held in residual status, and thorough in depth analysis, residual satellites are returned to the constellation every six months to ensure PNT [Position, Navigation, and Timing] operational capability. (James 2009)

The GAO report was also brought into question by the Air Force Times in an interview with Cristina Chaplain, the GAO representative who led the report team. ―In the wake of it all, the GAO's Cristina Chaplain, who oversaw the investigation, now says she regrets the ―turmoil" the report has caused for the Air Force. She says this while standing by her team's findings, which she notes the Pentagon ―fundamentally" concurred with in a letter attached to the report (Iannotta 2009).

GPS is a dual-use system in that it is employed by both military and civilian users. The reader should understand that, while it is considered dual-use, GPS transmits at two levels of service: Standard Positioning Service (SPS) and Precise Positioning Service (PPS). The military is directed to use PPS by U.S. Code. ―Expressed retention of PPS as a military of use system is also, in fact, U.S. law as of 1998 via U.S. Code Title 10 Section 2281" (Kelly 2006). PPS provides increased accuracy as well as an encrypted signal to prevent spoofing (the intentional alteration of a signal prior to its reception). (See figure 3 for the progression of GPS receivers used by the U.S. Army).

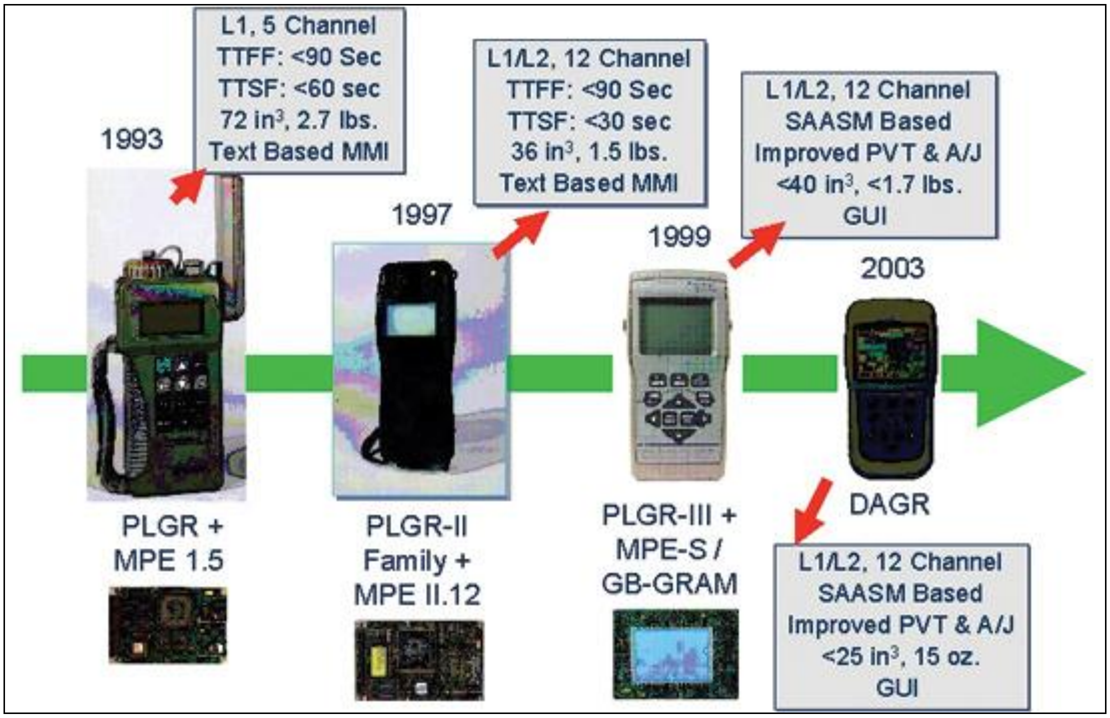


Figure 3. Progression of PPS Capable U.S. Military GPS Receivers
Source: John Kelly, ―PPS vs SPS: Why military applications require PPS," *GPS World* (January 2006): 1-8, http://www.gpsworld.com/gps/system-challenge/pps-versus-sps-996?page_id=1 (accessed 30 September 2009).
Note: (A/J – Anti-Jam, MPE – Miniature GPS Precision Lightweight Engine, PVT – Position, Velocity, and Timing, SAASM – Selective Availability Anti-Spoofing Module, TTFF – Time to First Fix, TTSF – Time To Subsequent Fix)

In order to use the Precision Positioning Service (PPS), the receiver must be loaded with cryptography (a system that allows only the receiver to understand the signal) in order to utilize the signal information. Without the cryptography, only the Standard Positioning Service (SPS) is received. Without encryption, the SPS signal remains susceptible to spoofing by an adversary. ―Use of commercial SPS receivers continues to be an issue in the Afghanistan and Iraq theaters. In a study conducted in 2006, AFSPC [Air Force Space Command] determined that many GPS-impacting interference events were unintentional and self-inflicted, and had a significant impact on

commercial (SPS) GPS receivers in theater” (Department of Defense 2008a, 22). Vulnerabilities to the GPS signal still exist even with encryption of the signal. Jamming and interference can just as easily deter effective use of the signal as spoofing. ―The GPS signal strength measured at the surface of the Earth is about-160dBw (1 x 10-16 watts), which is roughly equivalent to viewing a 25-watt light bulb from a distance of 10,000 miles. This weak signal can easily be blocked by destroying or shielding the GPS receiver’s antenna. The GPS signal can also be effectively jammed by a signal of a similar frequency but greater strength” (Johnston 2003, 1). Jamming can also occur through interference with own force systems. ―Commercial television, very high-frequency transmitters, aeronautical satellite communications and Mobile Satellite System terminals can also degrade GPS signals, and natural occurrences can cause interference that would pose distinct problems for users, including the military” (Adams 2001, 13). The trend towards increased usage of satellite and high frequency communications will continue to saturate the electromagnetic spectrum, thus making interference with the GPS signal a continuing challenge. Even the Department of Defense (DoD) in its 2008 GPS Report to Congress stated that, ―The potential harmful effects of interference on GPS services continue to justify attention from the DoD and civil agencies” (Department of Defense 2008a, 19).

Numerous systems within the US Army utilize GPS for its position, navigation, or timing information. Some of those systems include: weapon systems such as Multiple Launched Rocket System (MLRS); command and control systems such as Force XX1 Battle Command, Brigade and Below (FBCB2); fratricide prevention systems such as Blue Force Tracker (BFT); network systems such as the Network Time Server; and

logistics systems such as the Mobile Tracking System (MTS). One must note that there are two methods by which these systems acquire GPS data; GPS portable receivers and embedded GPS modules. In February 2009, the Assistant Secretary of the Army approved a memorandum directing installation of embeddable GPS in equipment that needs GPS but does not have a mobility requirement once put in place. —The memo titled "Embedded Global Positioning System (GPS)" directs that Army weapon systems that do not have a dismounted GPS requirement are to use embeddable GPS instead of handheld GPS effective 2012" (Pathfinder 2009, 3).

Historical Analysis

In looking back at the history of GPS, it is apparent that the technology has been around for quite some time. Its first use by the Army in combat operations was during Operation Desert Storm in 1991. The GPS constellation was not fully operational but allowed for 19 hours of coverage with a position error of 60 feet. In an October 1991 newsletter, the Center for Army Lessons Learned (CALL) noted only 500 demonstration receivers were owned by the Army at the outset of Operation Desert Shield (Dissinger 2008, 1). Times were much simpler then with limited navigation and limited availability. As technology became more complex and integrated in the Army infrastructure, GPS data was added virtually into every major system on the battlefield and in development. The Army had come to realize that fighting without GPS was not an option. —Without assured access to space, the U.S. military could not effectively conduct military operations on land, at sea, or in the air" (Pfaltzgraff 2009, 6). The rebuttal to the possibility of losing —assured access to space" is that —the GPS constellation continues to

age, but continues to function at or above U.S. Government (USG) published levels of performance (Department of Defense 2008a, 1).

When the U.S. Army went to Operation Enduring Freedom (OEF), every soldier either directly interfaced with or was supported by GPS data. Every element of combat power utilizes GPS: movement and maneuver, fires, intelligence, protection, command and control, and sustainment (Department of the Army 2008a, 4-1). This is not an unknown phenomenon with respect to technology. As the Army learns more about any technology, they seek out ways to apply that technology to maintain battlefield superiority. It has been no different with the application of GPS technology. At what point does the technology opportunity become necessity? ―The disciplined and informed application of lethal and nonlethal force is a critical contributor to successful Army operations and strategic success" (Department of the Army 2008a, 1-19). On the battlefield of today, lightning-fast response to time-sensitive intelligence demands exact information with regard to position and timing. The usage of precision guided munitions (PGMs) to meet surgical strike requirements allows battlefield commanders to limit collateral damage if they have the time available. In order to utilize GPS data within PGMs, it must first be generated. While the targeting process can be expedited, accuracy will be affected as a result. According to LTC Christopher F. Bentley, the Army Deputy Fire Support Coordinator during Operation Anaconda [March 2002], ―Although PGMs give the U.S. military an unparalleled ability to strike any point on the earth precisely, the time required to mensurate a target's coordinates and determine the DMPI [Decided Mean Point of Impact] to ensure the PGMs can hit the target is generally a luxury troops in contact don't have" (Kaufman 2003, 9). LTC Bentley went on to say, ―In many cases,

unguided munitions provide the same effects in a more timely manner and with greater economy than guided weapons" (Kaufman 2003, 17).

Without satellites in space, many of the precision strikes or rapid knowledge of troop maneuvers battlefield commanders depend on would not be possible. Up through 2006, the GPS Satellites have successfully met the world's needs for GPS data. According to the Government Accounting Office (GAO), that trend is in danger. The GAO report 09-325 predicts that a recent trend in delays (see figure 4) indicates a possibility of not maintaining availability in the future.

Table 3: Delays in Delivery of GPS Operational Functionality

Function or capability enabled	Original ground control program/version	Current or future ground control program/version	Amount of delay (in months)
GPS IIR-M satellites (first launch in 2005 & currently being launched)			
Command & telemetry for IIA & IIR and satellites, and use of additional signals	OCS Version 5.0 September 2005	OCS Version 5.2.1 September 2007	24
Command & telemetry for IIRM & IIF satellites	OCS Version 5.0 September 2005	AEP Version 5.2.2 March 2008	30
Selective Availability Anti-Spoofing Module	OCS Version 5.0 September 2005	AEP Version 5.5 September 2009	48
Second civil signal (L2C)	OCS Version 6 September 2007	OCX Block I or II September 2012/September 2013	60-72
Military code (M-code)	OCS Version 6 September 2007	OCX Block I or II September 2012/September 2013	60-72
GPS IIF satellites (first launch planned for November 2009)			
Third civil signal (L5)	OCS Version 6 September 2007	OCX Block I or II September 2012/September 2013	60-72

Source: GPS program office.

Figure 4. Delays in Delivery of GPS Operational Functionality
Source: Government Accounting Office (GAO), GAO 09-325, *Global Positioning System* (Washington, DC: Government Printing Office, 2009), 27.

The GAO report also stated that ―By delaying the delivery of ground control capabilities, the Air Force has created an imbalance between the capabilities offered by GPS satellites and the ability to exploit and make operational these capabilities through the ground control segment (Government Accounting Office 2009, 27). In addition, in the past five years there has been an exponential increase in space debris–mostly in Low Earth Orbit (LEO) but still a danger for the Medium Earth Orbit (MEO) satellites, especially during any craft's initial transit to orbit. A large amount of this debris was caused by the Chinese satellite destruction on January 11, 2007 (David 2007, 1). Lastly, while not man-made, cyclical ―space weather" can deny effective transmission of GPS data from space. Space weather can be caused by solar flares and sun spots which irradiate the atmosphere and disrupt the transmitted GPS signal. Historically, solar cycles occur every 11 years. Dr. Genene Fisher of the American Meteorological Society states that ―Just as society takes for granted that electricity, heat, and clean water will be available, they also take for granted that GPS will be available, reliable, and accurate" (Fisher 2009, 1). She also stated that, ―it is understood that space weather is the single largest contributor to single-frequency GPS errors" (Fisher 2009, 1).

Survey Analysis

The survey was distributed to 266 Army majors within Class 2009-02 at the U.S. Army Command and General Staff College. Of the 266 surveys distributed, 66 responses were received. This produced a 95 percent confidence interval. That is, if re-sampling were conducted, there is a greater than 95 percent chance that the content of the responses to the survey questions would be the same (Bitters 2009). With the response split almost evenly between combat arms and support branches, it can be interpreted that the opinions

are not skewed or biased towards either branch category. It bears repeating that, while the responses are quantitatively analyzed, they are strictly opinion and have in no way been vetted against any training records or personnel files.

The statistical analysis utilized the Pearson chi-squared test to determine if any significant difference existed when investigating for correlation between three key questions and four factors. “The chi-squared test, as a non-parametric test, is used in situations to substitute for parametric techniques when one of the following occurs: one, the data do not meet the assumptions for a standard parametric test, and two, the data consist of nominal or ordinal measurements, so that it is impossible to compute standard descriptive statistics such as the mean and standard deviation” (Gravetter 2009, 629). The data from this survey fall into the second category and thus the reason for utilizing the chi-squared test to determine if the difference between expected and actual results were merely the result of chance or if some significant relationship existed. The final question of the survey was specifically asked to discern whether or not the respondent felt that GPS was critical to the success of their mission. The interpretation of the final question’s responses also indirectly establishes whether or not a balance exists between dependence on GPS and TTPs. One caveat is that one must assume that those who answered “no” felt comfortable in either their capability to operate without GPS or had been trained in TTPs that contributed to success in a GPS degraded environment.

The table at the beginning of the Appendix B section titled Analysis by SPSS Software shows the p values for the chi-squared tests performed between four factors and three questions from the survey. The p value is a result derived from a standard table

using the inputs of the chi-squared calculation and the pre-determined level of significance.

> To determine if the chi-square value indicates a significant relationship, one must examine the probability [p value] that the distribution of answers occurred by chance alone. The conventional probability level used to answer this question is .05. If the probability is greater than .05 then the variables are not significantly related. If the probability is less than or equal to .05 then the variables are significantly related. For SPSS, the term significance is used in place of probability. The chi-square test table column ―Asymp. Sig” lists the probability (Arkkelin).

The p-value comparison only indicates whether or not a significant relationship exists between the compared variables. It does not measure the level of effect or significance present.

The following paragraphs explain the statistical analysis of the survey data:

1. Relationship between ―Branch” and the question ―Did you conduct land navigation in your last unit?” With a p-value greater than .05 (.753), a significant relationship between these two items did not exist. The crosstab results reinforce this finding in that the answers by branch were evenly spread across each branch category.

2. Relationship between ―Branch” and the question ―Have you used a personal GPS device while deployed?” With a p-value greater than .05 (.290), a significant relationship between these two items did not exist. The crosstab results seemed to indicate the contrary in that a large percentage of the combat arms branch answered yes to the question although, in further examination, the percentage within each branch answering yes did not significantly differ.

3. Relationship between ―Branch” and the question ―In your opinion, if GPS data was lost would it impact your ability to complete your assigned mission?” With a p-value greater than .05 (.958), a significant relationship between these two items did not exist.

The crosstab results reinforced this finding in that they were evenly dispersed between those answering yes and no.

4. Relationship between ―Number of years you have been an Army Officer" and the question ―Did you conduct land navigation training in your last unit?" With a p-value greater than .05 (.171), a significant relationship between these two items did not exist. The crosstab results show that two values were less than 5 which tend to skew the calculation since the chi-squared calculation becomes less reliable when values used are less than 5.

5. Relationship between ―Number of years you have been an Army Officer" and the question ―Have you used a personal GPS device while deployed?" With a p-value greater than .05 (.165), a significant relationship between these two items did not exist. The crosstab results show that two values were less than 5 which tend to skew the calculation but not to the point where they lead the reader to a different conclusion.

6. Relationship between ―Number of years you have been an Army Officer" and the question ―In your opinion, if GPS data was lost would it impact your ability to complete your assigned mission?" With a p-value greater than .05 (.726), a significant relationship between these two items did not exist. The crosstab results did not demonstrate any skewed result which would disagree with the p-value relationship conclusion.

7. Relationship between ―The last time you completed formal land navigation training" and the question ―Did you conduct land navigation training in your last unit?" With a p-value less than .05 (.000), a significant relationship between these two items did exist. The crosstab results confirm this relationship however, upon further examination,

there appears to be an issue with the comparison of a three-element ordinal question (two, three to five, more than five years) to a yes/no question (last unit or not). The comparison was pre-disposed to a high p-value since both questions ask if navigation training was conducted.

8. Relationship between “The last time you completed formal land navigation training” and the question “Have you used a personal GPS device while deployed?” With a p-value greater than .05 (.201), a significant relationship between these two items did not exist. The crosstab results confirm this result in that those officers who answered yes were evenly spread across the range of time since last conducting formal land navigation training.

9. Relationship between “The last time you completed formal land navigation training” and the question “In your opinion, if GPS data was lost would it impact your ability to complete your assigned mission?” With a p-value greater than .05 (.322), a significant relationship between these two items did not exist. The crosstab results across the range of years since last formal navigation training did not demonstrate any skewed results that would lead the reader to contradicting the p-value comparison conclusion.

10. Relationship between “For the last formal land navigation exercise, did you complete it individually or as part of a group/team” and the question “Did you conduct land navigation training in your last unit?” With a p-value greater than .05 (.566), a significant relationship between these two items did not exist. The crosstab results did not contradict the p-value comparison conclusion.

11. Relationship between “For the last formal land navigation exercise, did you complete it individually or as part of a group/team” and the question “Have you used a

personal GPS device while deployed?” With a p-value greater than .05 (.949), a significant relationship between these two items did not exist. The crosstab results were evenly distributed between those conducting land navigation training as a group and as an individual which reinforced the conclusion of no significant relationship.

12. Relationship between ―For the last formal land navigation exercise, did you complete it individually or as part of a group/team” and the question ―In your opinion, if GPS data was lost would it impact your ability to complete your assigned mission?” With a p-value greater than .05 (.838), a significant relationship between these two items did not exist. While the crosstab results did show a larger number of officers completed land navigation as an individual this did not appear to effect the percentage of those answering yes or no to loss of GPS impacting mission completion.

The chi-squared test results did not indicate any significant correlation between the survey questions except for the comparison between ―The last time you completed formal land navigation training” and the question ―Did you conduct land navigation training in your last unit?” which should be considered an invalid comparison based on the analysis.

The GPS system is complex. The descriptive analysis indicated GPS is in use by multiple systems throughout the Army. With the vulnerabilities that exist to the GPS signal, a significant amount of risk exists in the ability to maintain an accurate and dependable signal. There are control measures in place which mitigate some, but not all of the vulnerabilities. The historical analysis exposed the strong performance of the GPS system as a whole. A critical point to note is that even though the system performed well in the past this does not serve as a clear indicator of future performance as pointed out by

GAO Report 09-325. Also, the trend of increasing GPS usage and integration in Army systems clearly shows increasing dependency and that GPS data has become a critical force multiplier for success on the battlefield. The survey data analysis did not indicate any valid correlations between the questions. Based on this analysis, chapter 5 will deliver the conclusions as well as recommendations for further research.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The purpose of this thesis was to determine if today's U.S. Army officers believe that the Army is unbalanced in its dependence on GPS data. The thesis also served to investigate what the appropriate balance was between the use of GPS technology and TTPs that do not rely on GPS to allow the U.S. Army to fight through a degradation of GPS. The limitation of this thesis to unclassified information sources prevented consideration of classified sources. An in-depth review of U.S. Army field manuals and a survey of experienced Army field grade officers sought to mitigate that limitation.

The field manuals did not present non-GPS options except for Field Manual 3-25.26, *Map Reading and Land Navigation*. Also, U.S. Army Field Manual 3-20.98, *Reconnaissance and Scout Platoon,* was the only field manual that reminded the reader to be aware of overdependence on GPS data.

> A unit that relies too heavily on systems such the FBCB2 and GPS devices will find its capabilities severely degraded if these systems fail. The unit will be unable to maintain situational awareness. To prevent potential dangers when system failure occurs, the platoon must ensure it can use a balance of technology and traditional basic Soldier skills in observation, navigation, and other critical activities. (Department of the Army 2009, D-3)

While one field manual mentioning alternatives to GPS does not clearly indicate an over dependence on GPS, it does point out the need for increased Army awareness to vulnerabilities that may preclude its use.

As noted earlier, results of the survey did not indicate a perception of over-reliance on GPS. However, one can infer from the descriptive and historical analysis that

a large measure of dependence on GPS does exist. Even though dependence exists, one cannot make the leap to overdependence based on the analysis conducted. It is true that GPS data usage is thoroughly integrated into many Army systems as evidenced by its use in precision guided weapons, timing in computer information systems, position information in command and control and logistics systems, and maneuver information for air and land battlefield vehicles. Still, even with a high level of GPS data integration and usage, the answer to the primary research question of whether or not U.S. Army officers believe the Army is unbalanced in its dependency on GPS is no. The secondary research question of appropriate balance between technology and TTPs to allow the U.S. Army to fight through a degradation of GPS was answered by the respondents in that they did not perceive an inappropriate balance and over reliance on GPS with regard to its necessity in completing their missions. The testing did not reveal any significant result upon which one could conclude the balance was not appropriate. A limitation of the data collected is that it is based on opinion and experience. While both are respectable, it must be made clear that the data and information presented from practitioners in the GPS field represents their interpretation of the vulnerabilities of GPS and not the actual impact of real world events.

Another key point to bring up is the number of systems that utilize GPS data and the lack of redundant capabilities that would allow the commander to successfully execute his mission. If GPS data reception is lost, the systems that utilize it must resort to other, less precise methods of positioning, navigation, and timing. All of these methods are less accurate and can take more time to complete. As discussed in chapter 4, numerous vulnerabilities exist that can deny the use of GPS data. A number of these

vulnerabilities are out of the control of systems or battlefield personnel (such as space weather, space debris, and others). While information is available to predict some events that would limit GPS availability or reliability, the battlefield commander must understand and prepare for these events. The cascading effect of GPS loss would have a total force effect and requires careful and pre-determined actions to successfully operate in a degraded condition.

Recommendations

With respect to GPS, Army doctrine needs more consideration. Those who utilize Army doctrine need to appreciate the risks and vulnerabilities of GPS technology. Due to its pervasive use across the Army, all soldiers need to understand its limitations. In addition, those systems that would act as secondary and tertiary backups in case of GPS degradation or loss need to be included in doctrine in appreciation of those vulnerabilities that are out of the user's control. The impact of including limitations, vulnerabilities, and backup systems into existing land navigation training would be minimal. Coordination between the U.S. Army Training and Doctrine Command (TRADOC) and the U.S. Army Space and Missile Defense Command (SMDC) would ensure that up-to-date information is conveyed to the force.

Research into upgrading and hardening GPS receivers and satellites must continue in order to sustain the technological advantage soldiers currently experience on the battlefield. With that said, commanders need to have a backup plan in case GPS is lost. With so many systems and lives relying on one system's performance, operating without some type of risk mitigating strategy will not ensure success. Future research in this area should include:

1. GPS loss risk mitigation strategies and their effectiveness. This research would be an excellent candidate for units operating at the National Training Centers (NTC) where loss of GPS could be implemented in a controlled environment and studied for possible risk strategies.

2. Development of battle drills to address loss of GPS. This research would be most beneficial when studied at the lowest tactical unit size level possible. A study of one unit and their proficiency in performance through loss of GPS or a comparison study between similar units could provide best practices to the rest of the force.

3. Effect of a localized Electromagnetic pulse (EMP) on GPS availability. For the greatest benefit, this research would need to be done at a classified level. While not directly addressed by this thesis, an EMP poses a credible threat to GPS receiving equipment on the battlefield. Emphasis on future capabilities and vulnerabilities compared to current GPS receiver capability could result in development of more robust equipment for the force.

4. Effect of other country's position information satellites (GLONASS, Galileo, Compass) on GPS. Research into multi-frequency receivers and the cost and benefit associated with utilizing multiple systems could create backup strategies in case the NAVSTAR system is unavailable.

5. Redundant Land-based navigation systems. In case of GPS system degradation or total loss, investigation into systems that can act as secondary or tertiary backup that would provide adequate and timely information for the mission to succeed.

These recommended future research efforts should be notable in their different character, compared to this research. While this research sought largely subjective

answers based on experience, there is a need to develop more definitive answers about what really could happen in a hostile environment, if a determined and capable adversary sought to deny US Forces the use of GPS to provide an accuracy advantage in targeting, navigation, and system synchronization. This implies a more empirical, quantitative methodology that provides repeatable results and high confidence in the reliability of the objective data.

APPENDIX A

SURVEY

Map Reading and Land Navigation

Hello,
I am a Naval Officer attending the US Army Command and General Staff College. I am conducting research on Army use of Global Positioning System (GPS) data.
Your input is important for this research. The survey will take approximately 5-10 minutes. Participation is voluntary. All information collected is confidential and will be used solely for this research without personally identifying information.
Thank you for your assistance.
Map Reading
and
Land Navigation
This Survey has been approved by the Command and General Staff College Qaulity Assurance Office.
Survey Control Number is 09-081
POC: thomas.m.mcgrath@us.army.mil

1. Please indicate your branch.
{Choose one}
( ) Combat Arms
( ) Combat Support
( ) Combat Service Support

2. Please indicate the number of years you have been an Army Officer.
{Choose one}
( ) Less than 5
( ) Between 5 and 10
( ) Between 10 and 15
( ) More than 15

3. Please indicate the last time you completed formal land navigation training.
{Choose one}
( ) Less than 2 years
( ) Between 3 to 5 years
( ) More than 5 years

4. Did you conduct land navigation training in your last unit?
{Choose one}
( ) Yes
( ) No

5. Have you used a personal GPS device while deployed?
{Choose one}
( ) Yes
( ) No

6. For your last formal land navigation exercise, did you complete it individually or as part of a group/team?
{Choose one}
( ) Individually
( ) Group/Team

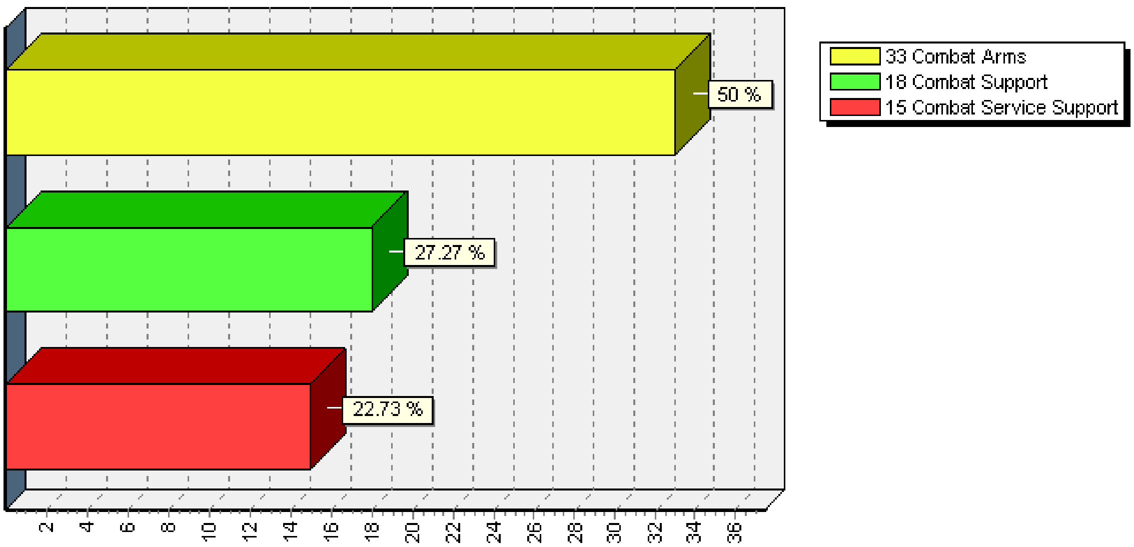
7. In your opinion, if GPS data was lost would it impact your ability to complete your assigned mission?
{Choose one}
( ) Yes
( ) No
Comments:

APPENDIX B

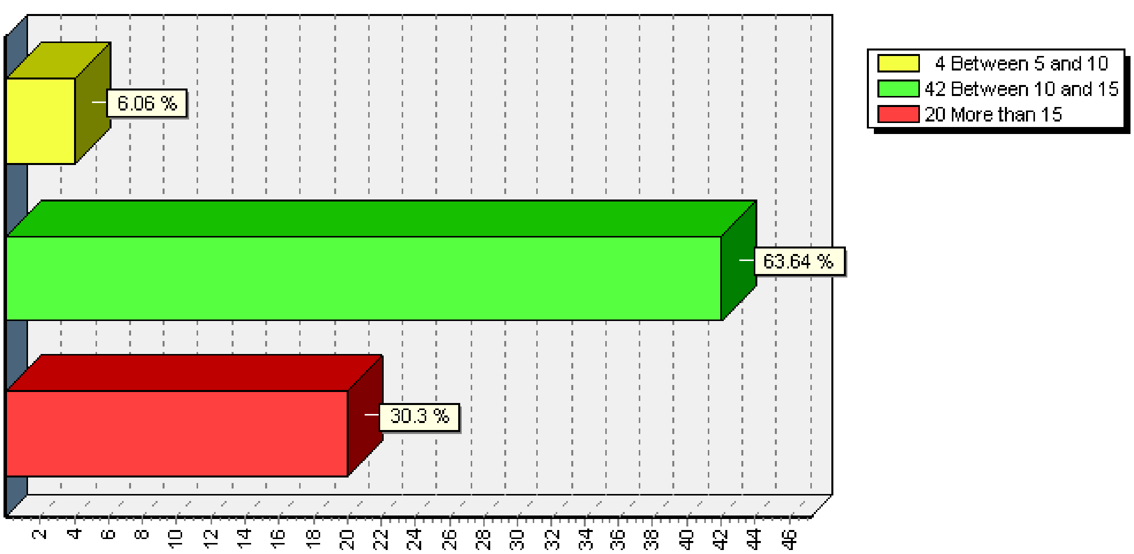
SURVEY ANALYSIS

Bar Graphs
Map Reading and Land Navigation

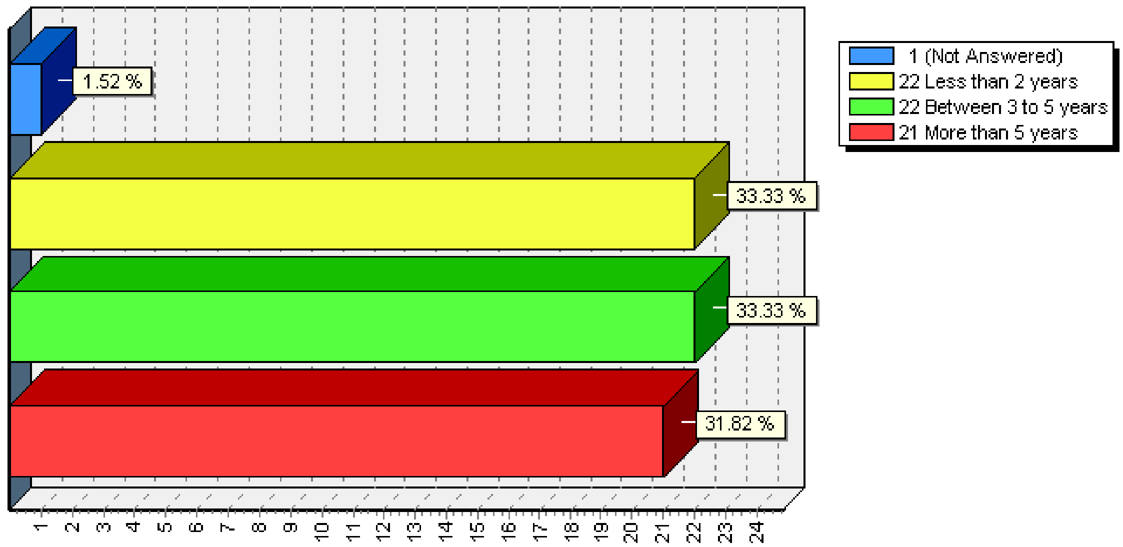
Please indicate your branch.



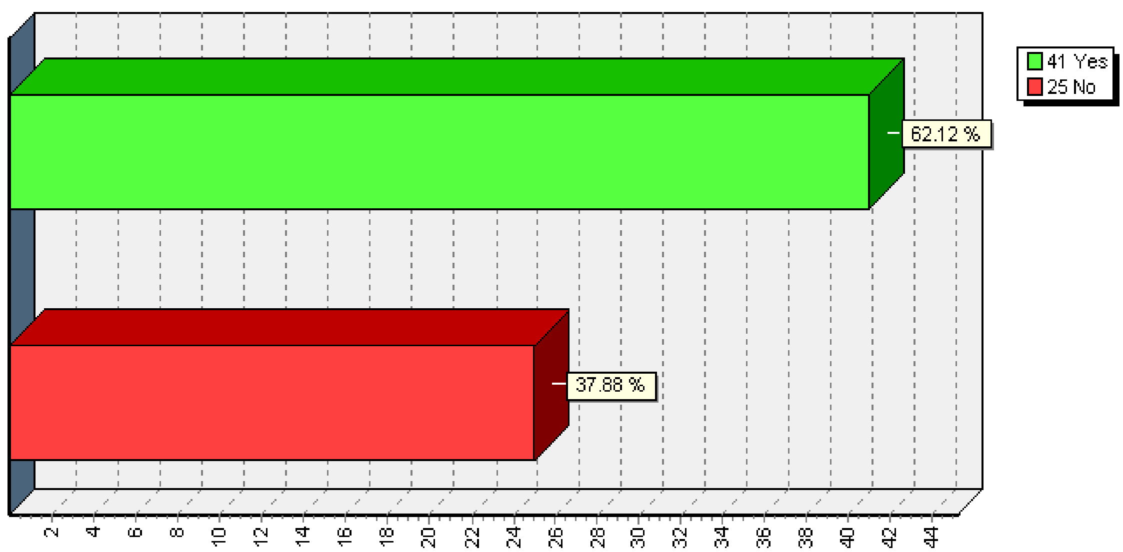
Please indicate the number of years you have been an Army Officer.



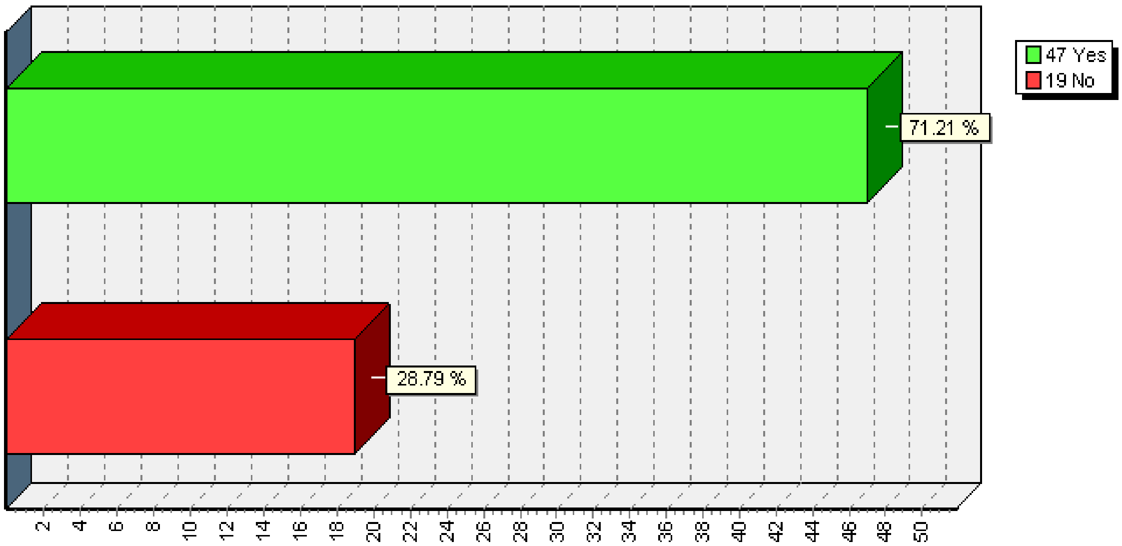
Please indicate the last time you completed formal land navigation training.



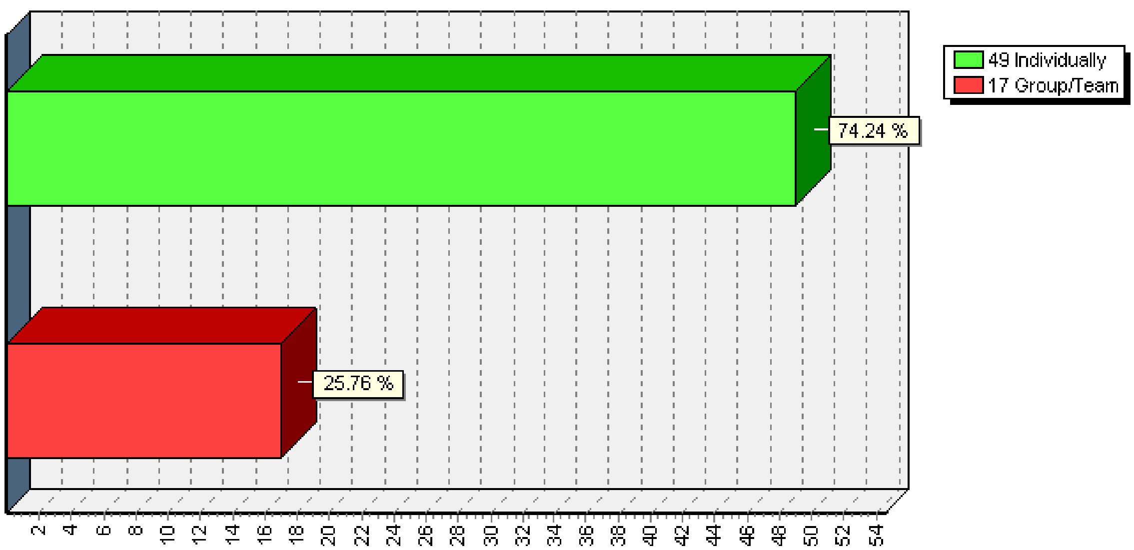
Did you conduct land navigation training in your last unit?



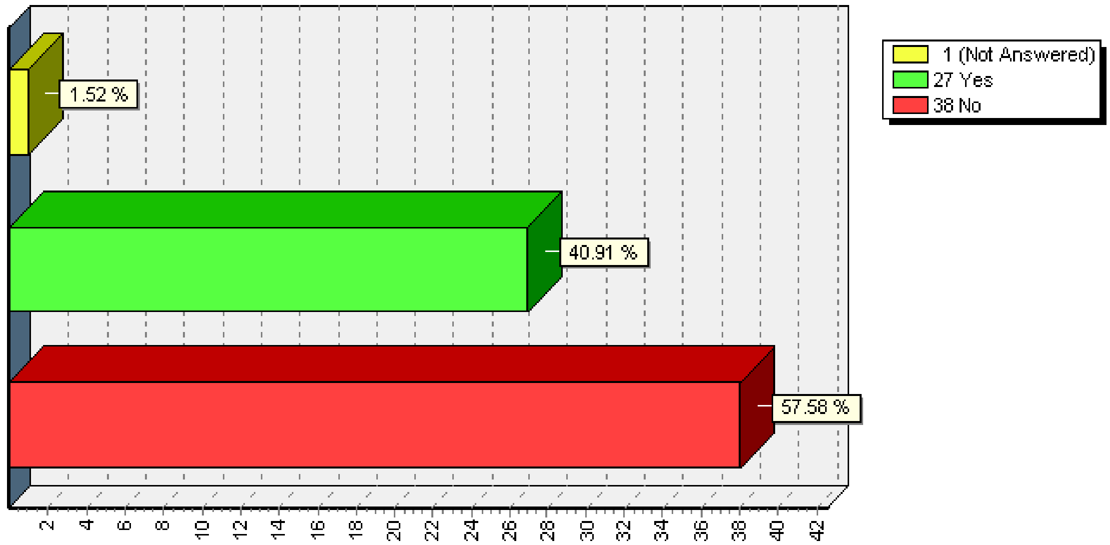
Have you used a personal GPS device while deployed?



For your last formal land navigation exercise, did you complete it individually or as part of a group/team?



In your opinion, if GPS data was lost would it impact your ability to complete your assigned mission?



Analysis by SPSS Software

P-VALUE CHART	Did you conduct land navigation training in your last unit?	Have you used a personal GPS device while deployed?	In your opinion, if GPS data was lost would it impact your ability to complete your assigned mission?
Please Indicate Branch	0.753	0.290	0.958
Please indicate the number of years you have been an Army Officer	0.171	0.165	0.726
Please indicate the last time you completed formal land navigation training.	0.000	0.201	0.322
For your last formal land navigation exercise, did you complete it individually or as part of a group/team?	0.566	0.949	0.838

P-Value smaller than .05 indicates significant relationship. **Note** - it does not indicate the level of significance of the relationship.

Crosstab

			Did you conduct land navigation training in your last unit?		
			Yes	No	Total
Please indicate your branch.	Combat Arms	Count	19	14	33
		Expected Count	20.2	12.8	33.0
		% within Please indicate your branch.	57.6%	42.4%	100.0%
	Combat Support	Count	11	7	18
		Expected Count	11.0	7.0	18.0
		% within Please indicate your branch.	61.1%	38.9%	100.0%
	Combat Service Support	Count	11	5	16
		Expected Count	9.8	6.2	16.0
		% within Please indicate your branch.	68.8%	31.3%	100.0%
Total		Count	41	26	67
		Expected Count	41.0	26.0	67.0
		% within Please indicate your branch.	61.2%	38.8%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	.567[a]	2	.753
Likelihood Ratio	.576	2	.750
Linear-by-Linear Association	.536	1	.464
N of Valid Cases	67		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 6.21.

Crosstab

			Have you used a personal GPS device while deployed?		Total
			Yes	No	
Please indicate your branch.	Combat Arms	Count	25	8	33
		Expected Count	23.6	9.4	33.0
		% within Please indicate your branch.	75.8%	24.2%	100.0%
	Combat Support	Count	14	4	18
		Expected Count	12.9	5.1	18.0
		% within Please indicate your branch.	77.8%	22.2%	100.0%
	Combat Service Support	Count	9	7	16
		Expected Count	11.5	4.5	16.0
		% within Please indicate your branch.	56.3%	43.8%	100.0%
Total		Count	48	19	67
		Expected Count	48.0	19.0	67.0
		% within Please indicate your branch.	71.6%	28.4%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.474[a]	2	.290
Likelihood Ratio	2.351	2	.309
Linear-by-Linear Association	1.584	1	.208
N of Valid Cases	67		

a. 1 cells (16.7%) have expected count less than 5. The minimum expected count is 4.54.

Crosstab

			In your opinion, if GPS data was lost would it impact your ability to complete your assigned mission?		Total
			Yes	No	
Please indicate your branch.	Combat Arms	Count	13	20	33
		Expected Count	13.5	19.5	33.0
		% within Please indicate your branch.	39.4%	60.6%	100.0%
	Combat Support	Count	7	10	17
		Expected Count	7.0	10.0	17.0
		% within Please indicate your branch.	41.2%	58.8%	100.0%
	Combat Service Support	Count	7	9	16
		Expected Count	6.5	9.5	16.0
		% within Please indicate your branch.	43.8%	56.3%	100.0%
Total		Count	27	39	66
		Expected Count	27.0	39.0	66.0
		% within Please indicate your branch.	40.9%	59.1%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	.085[a]	2	.958
Likelihood Ratio	.085	2	.958
Linear-by-Linear Association	.083	1	.773
N of Valid Cases	66		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 6.55.

Crosstab

			Did you conduct land navigation training in your last unit?		
			Yes	No	Total
Please indicate the number of years you have been an Army Officer.	Between 5 and 10	Count	4	0	4
		Expected Count	2.4	1.6	4.0
		% within Please indicate the number of years you have been an Army Officer.	100.0%	.0%	100.0%
	Between 10 and 15	Count	23	19	42
		Expected Count	25.7	16.3	42.0
		% within Please indicate the number of years you have been an Army Officer.	54.8%	45.2%	100.0%
	More than 15	Count	14	7	21
		Expected Count	12.9	8.1	21.0
		% within Please indicate the number of years you have been an Army Officer.	66.7%	33.3%	100.0%
Total		Count	41	26	67
		Expected Count	41.0	26.0	67.0
		% within Please indicate the number of years you have been an Army Officer.	61.2%	38.8%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3.533[a]	2	.171
Likelihood Ratio	4.918	2	.086
Linear-by-Linear Association	.033	1	.857
N of Valid Cases	67		

a. 2 cells (33.3%) have expected count less than 5. The minimum expected count is 1.55.

Crosstab

			Have you used a personal GPS device while deployed?		Total
			Yes	No	
Please indicate the number of years you have been an Army Officer.	Between 5 and 10	Count	4	0	4
		Expected Count	2.9	1.1	4.0
		% within Please indicate the number of years you have been an Army Officer.	100.0%	.0%	100.0%
	Between 10 and 15	Count	27	15	42
		Expected Count	30.1	11.9	42.0
		% within Please indicate the number of years you have been an Army Officer.	64.3%	35.7%	100.0%
	More than 15	Count	17	4	21
		Expected Count	15.0	6.0	21.0
		% within Please indicate the number of years you have been an Army Officer.	81.0%	19.0%	100.0%
Total		Count	48	19	67
		Expected Count	48.0	19.0	67.0
		% within Please indicate the number of years you have been an Army Officer.	71.6%	28.4%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3.598[a]	2	.165
Likelihood Ratio	4.707	2	.095
Linear-by-Linear Association	.158	1	.691
N of Valid Cases	67		

a. 2 cells (33.3%) have expected count less than 5. The minimum expected count is 1.13.

Crosstab

			In your opinion, if GPS data was lost would it impact your ability to complete your assigned mission?		
			Yes	No	Total
Please indicate the number of years you have been an Army Officer.	Between 5 and 10	Count	1	3	4
		Expected Count	1.6	2.4	4.0
		% within Please indicate the number of years you have been an Army Officer.	25.0%	75.0%	100.0%
	Between 10 and 15	Count	18	23	41
		Expected Count	16.8	24.2	41.0
		% within Please indicate the number of years you have been an Army Officer.	43.9%	56.1%	100.0%
	More than 15	Count	8	13	21
		Expected Count	8.6	12.4	21.0
		% within Please indicate the number of years you have been an Army Officer.	38.1%	61.9%	100.0%
Total		Count	27	39	66
		Expected Count	27.0	39.0	66.0
		% within Please indicate the number of years you have been an Army Officer.	40.9%	59.1%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	.640[a]	2	.726
Likelihood Ratio	.666	2	.717
Linear-by-Linear Association	.000	1	.984
N of Valid Cases	66		

a. 2 cells (33.3%) have expected count less than 5. The minimum expected count is 1.64.

Crosstab

			Did you conduct land navigation training in your last unit?		
			Yes	No	Total
Please indicate the last time you completed formal land navigation training.	Less than 2 years	Count	22	0	22
		Expected Count	13.7	8.3	22.0
		% within Please indicate the last time you completed formal land navigation training.	100.0%	.0%	100.0%
	Between 3 to 5 years	Count	14	8	22
		Expected Count	13.7	8.3	22.0
		% within Please indicate the last time you completed formal land navigation training.	63.6%	36.4%	100.0%
	More than 5 years	Count	5	17	22
		Expected Count	13.7	8.3	22.0
		% within Please indicate the last time you completed formal land navigation training.	22.7%	77.3%	100.0%
Total		Count	41	25	66
		Expected Count	41.0	25.0	66.0
		% within Please indicate the last time you completed formal land navigation training.	62.1%	37.9%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	27.945[a]	2	.000
Likelihood Ratio	35.154	2	.000
Linear-by-Linear Association	27.490	1	.000
N of Valid Cases	66		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 8.33.

Crosstab

			Have you used a personal GPS device while deployed?		
			Yes	No	Total
Please indicate the last time you completed formal land navigation training.	Less than 2 years	Count	18	4	22
		Expected Count	16.0	6.0	22.0
		% within Please indicate the last time you completed formal land navigation training.	81.8%	18.2%	100.0%
	Between 3 to 5 years	Count	17	5	22
		Expected Count	16.0	6.0	22.0
		% within Please indicate the last time you completed formal land navigation training.	77.3%	22.7%	100.0%
	More than 5 years	Count	13	9	22
		Expected Count	16.0	6.0	22.0
		% within Please indicate the last time you completed formal land navigation training.	59.1%	40.9%	100.0%
Total		Count	48	18	66
		Expected Count	48.0	18.0	66.0
		% within Please indicate the last time you completed formal land navigation training.	72.7%	27.3%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3.208[a]	2	.201
Likelihood Ratio	3.134	2	.209
Linear-by-Linear Association	2.821	1	.093
N of Valid Cases	66		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 6.00.

Crosstab

			In your opinion, if GPS data was lost would it impact your ability to complete your assigned mission?		
			Yes	No	Total
Please indicate the last time you completed formal land navigation training.	Less than 2 years	Count	10	12	22
		Expected Count	8.8	13.2	22.0
		% within Please indicate the last time you completed formal land navigation training.	45.5%	54.5%	100.0%
	Between 3 to 5 years	Count	6	16	22
		Expected Count	8.8	13.2	22.0
		% within Please indicate the last time you completed formal land navigation training.	27.3%	72.7%	100.0%
	More than 5 years	Count	10	11	21
		Expected Count	8.4	12.6	21.0
		% within Please indicate the last time you completed formal land navigation training.	47.6%	52.4%	100.0%
Total		Count	26	39	65
		Expected Count	26.0	39.0	65.0

Crosstab

			In your opinion, if GPS data was lost would it impact your ability to complete your assigned mission?		
			Yes	No	Total
Please indicate the last time you completed formal land navigation training.	Less than 2 years	Count	10	12	22
		Expected Count	8.8	13.2	22.0
		% within Please indicate the last time you completed formal land navigation training.	45.5%	54.5%	100.0%
	Between 3 to 5 years	Count	6	16	22
		Expected Count	8.8	13.2	22.0
		% within Please indicate the last time you completed formal land navigation training.	27.3%	72.7%	100.0%
	More than 5 years	Count	10	11	21
		Expected Count	8.4	12.6	21.0
		% within Please indicate the last time you completed formal land navigation training.	47.6%	52.4%	100.0%
Total		Count	26	39	65
		Expected Count	26.0	39.0	65.0
		% within Please indicate the last time you completed formal land navigation training.	40.0%	60.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.266[a]	2	.322
Likelihood Ratio	2.329	2	.312
Linear-by-Linear Association	.015	1	.902
N of Valid Cases	65		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 8.40.

Crosstab

			Did you conduct land navigation training in your last unit?		Total
			Yes	No	
For your last formal land navigation exercise, did you complete it individually or as part of a group/team?	Individually	Count	31	18	49
		Expected Count	30.0	19.0	49.0
		% within For your last formal land navigation exercise, did you complete it individually or as part of a group/team?	63.3%	36.7%	100.0%
	Group/Team	Count	10	8	18
		Expected Count	11.0	7.0	18.0
		% within For your last formal land navigation exercise, did you complete it individually or as part of a group/team?	55.6%	44.4%	100.0%
Total		Count	41	26	67
		Expected Count	41.0	26.0	67.0
		% within For your last formal land navigation exercise, did you complete it individually or as part of a group/team?	61.2%	38.8%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.330[a]	1	.566		
Continuity Correction[b]	.085	1	.771		
Likelihood Ratio	.326	1	.568		
Fisher's Exact Test				.584	.382
Linear-by-Linear Association	.325	1	.569		
N of Valid Cases	67				

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 6.99.

b. Computed only for a 2x2 table

Crosstab

			Have you used a personal GPS device while deployed?		
			Yes	No	Total
For your last formal land navigation exercise, did you complete it individually or as part of a group/team?	Individually	Count	35	14	49
		Expected Count	35.1	13.9	49.0
		% within For your last formal land navigation exercise, did you complete it individually or as part of a group/team?	71.4%	28.6%	100.0%
	Group/Team	Count	13	5	18
		Expected Count	12.9	5.1	18.0
		% within For your last formal land navigation exercise, did you complete it individually or as part of a group/team?	72.2%	27.8%	100.0%
Total		Count	48	19	67
		Expected Count	48.0	19.0	67.0
		% within For your last formal land navigation exercise, did you complete it individually or as part of a group/team?	71.6%	28.4%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.004[a]	1	.949		
Continuity Correction[b]	.000	1	1.000		
Likelihood Ratio	.004	1	.949		
Fisher's Exact Test				1.000	.603
Linear-by-Linear Association	.004	1	.949		
N of Valid Cases	67				

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 5.10.

b. Computed only for a 2x2 table

Crosstab

			In your opinion, if GPS data was lost would it impact your ability to complete your assigned mission?		
			Yes	No	Total
For your last formal land navigation exercise, did you complete it individually or as part of a group/team?	Individually	Count	20	28	48
		Expected Count	19.6	28.4	48.0
		% within For your last formal land navigation exercise, did you complete it individually or as part of a group/team?	41.7%	58.3%	100.0%
	Group/Team	Count	7	11	18
		Expected Count	7.4	10.6	18.0
		% within For your last formal land navigation exercise, did you complete it individually or as part of a group/team?	38.9%	61.1%	100.0%
Total		Count	27	39	66
		Expected Count	27.0	39.0	66.0
		% within For your last formal land navigation exercise, did you complete it individually or as part of a group/team?	40.9%	59.1%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.042[a]	1	.838		
Continuity Correction[b]	.000	1	1.000		
Likelihood Ratio	.042	1	.838		
Fisher's Exact Test				1.000	.534
Linear-by-Linear Association	.041	1	.839		
N of Valid Cases	66				

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 7.36.

b. Computed only for a 2x2 table

Source: Dr. David Bitters, U.S. Army Command and General Staff College, Quality Assurance Office, Statistician, 19 November 2009.

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